Vaporization

- Vapor: gas phase of a substance that is liquid at room temperature and atmospheric pressure
- Vaporization: conversion of liquid to gas (inside vaporizer)
- Vaporization depends on:
  - Vapor pressure of agent
  - Temperature of environment
  - Amount of carrier gas (N_2O & O_2) used

Saturated Vapor Pressure

- Liquid inside closed container
  - Molecules of liquid break away an enter space above to form a vapor
  - At constant Temp:
    - # molecules entering and leaving liquid are equal
    - # molecules in vapor phase stays constant
    - Pressure created when molecules “bombard” the walls of container→Saturated Vapor Pressure (SVP)
- Volatile Anesthetic Agent (VAA): liquid that has tendency to change to a vapor at standard temp & press.
  - Higher volatility = stronger tendency to change to vapor = higher SVP

SVP

- Methoxyflurane: 23mmHg
- Sevoflurane: 160mmHg
- Enflurane: 175mmHg
- Isoflurane: 238mmHg
- Halothane: 243mmHg
- Desflurane: 660mmHg

SVP and Temperature Changes

- Heat increases SVP
  - More molecules enter gas phase
  - Less molecules “re-enter” liquid phase
- Cooling decreases SVP
  - Less molecules enter gas phase
  - More molecules “re-enter” liquid phase

Carrier Gas (N_2O and O_2)

- Passing of carrier gas over the liquid decreases SVP
- Heat is needed continuously to vaporize anesthetic agents and maintain constant SVP
- When practitioner turns on vaporizer, carrier gas enter the vaporizer to “pick up” and deliver VAA to patient→ SVP decreases
- The liquid agent (e.g. Isoflurane) generates more vapor as an “inherent attempt” to keep SVP constant → heat is lost→decreased vaporizer output

Temperature Compensation

- Heat must be supplied to the liquid anesthetic inside vaporizer to maintain constant temperature→constant SVP

Vaporizer Classification

A. Method of regulating output concentration
   1. Concentration calibrated (variable-bypass)
   2. Measured flow (copper Kettle)
B. Method of vaporization
   1. Flow over
   2. Bubble Through
   3. Injection
C. Temperature compensation
   1. Thermocompensation
   2. Supplied heat
D. Specificity
   1. Agent specific
   2. Multiple agent
E. Resistance
   1. Plenum
   2. Low resistance

Method of regulating output concentration

Concentration Calibrated (Variable Bypass)

- Total carrier gas flow automatically divided into two paths
- One path flowing through vapor above liquid anesthetic
- The other bypassing the vapor chamber.
- The two flows meet and mix at the outflow tract. The concentration of the anesthetic determined by the flow ratio

Examples are:

Tec 3, 4, and 5 Vaporizers- Most common

Concentration Calibrated (Variable Bypass)

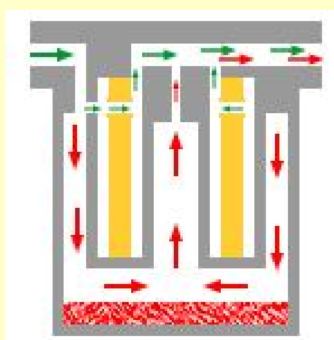
- The vaporizing chamber incorporates a network of internal channels and wicks which ensures that the gas emerging from the chamber is fully saturated with anesthetic vapor.
- The concentration of the anesthetic agent in this gas is therefore known (from its saturated vapor pressure) so, when this gas is mixed with the anesthetic-free bypass gas, the concentration of anesthetic in the gas leaving the vaporizer is also known.
- The proportion of the total gas flow passing through the vaporizing chamber is controlled by a dial which accurately indicates the concentration of the anesthetic delivered by the vaporizer
- If the dial of a Halothane vaporizer is turned to 2%, more carrier gas goes into the vaporizer chamber than if the dial is set at 1%

Changes in Temperature

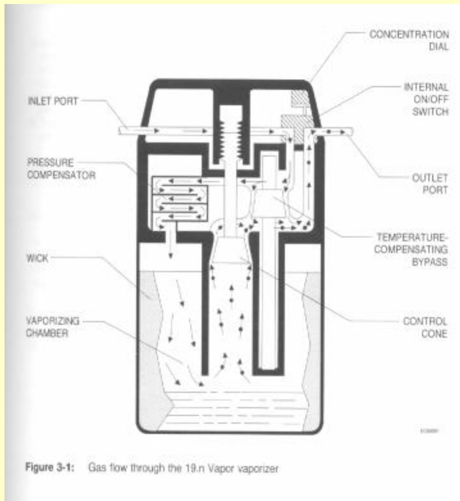
- Compensation for the effects of changes in temperature on the SVP (saturated vapor pressure) of the anesthetic may be achieved in a number of ways:
  - – Minimize temperature fluctuations by heavy copper construction (older "copper kettle" vaporizers) or bronze, stainless steel, and aluminum (newer vaporizers) which act as heat sink.
  - – Compensate for temperature changes by a valve that varies the proportion of the gas that flows through the vaporizing chamber

Vapor 19.n Vaporizer

An annular valve constructed of dissimilar metals increases flow through the bypass when temperature increases (automatically done by vaporizer)

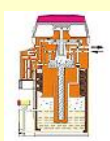


Basic Concentration calibrated, flow over, thermocompensation, agent specific, plenum vaporizers



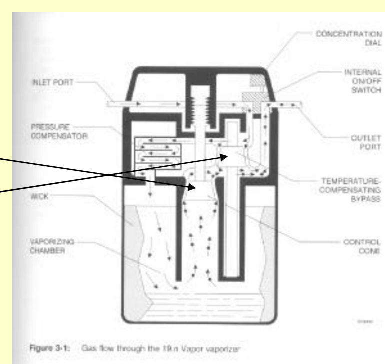
Drager
Vapor 19.n

Datex-Ohmeda
Tec 5



Vapor 19.n

- The fresh-gas stream is split into the dosage path and bypass path
- The stream through the dosage path is directly controlled by the control dial (control cone)
- The stream through the bypass is controlled by a temperature compensating bypass valve
- The gas flow is laminar over a wide flow range
- Additional components compensate back pressure fluctuations from the breathing circuit
- If the dial of a Halothane vaporizer is turned to 2%, more carrier gas goes into the vaporizer chamber than if the dial is set at 1%



Method of vaporization

Flow Over

- Carrier gas flows OVER liquid picking up vapor.
- Efficiency improved by increasing area that carrier gas flows over gas-liquid interface. ie. Baffles or wicks

Method of regulating output concentration

Measured Flow (Copper Kettle & Vernitrol)

- Also known as bubble through or Vernitrol.
- Flow meter-measured. Manually calculated bypassed carrier flow.
- Temperature compensated by construction materials with high specific heat and thermal conductivity to offset cooling from vaporization induced heat loss. ie. Copper
- Amount of carrier gas (CG) O2 bubbled through is determined by a dedicated Thorpe tube flowmeter
- A valve separates the vaporizer circuit from the standard O2 & N2O flowmeters

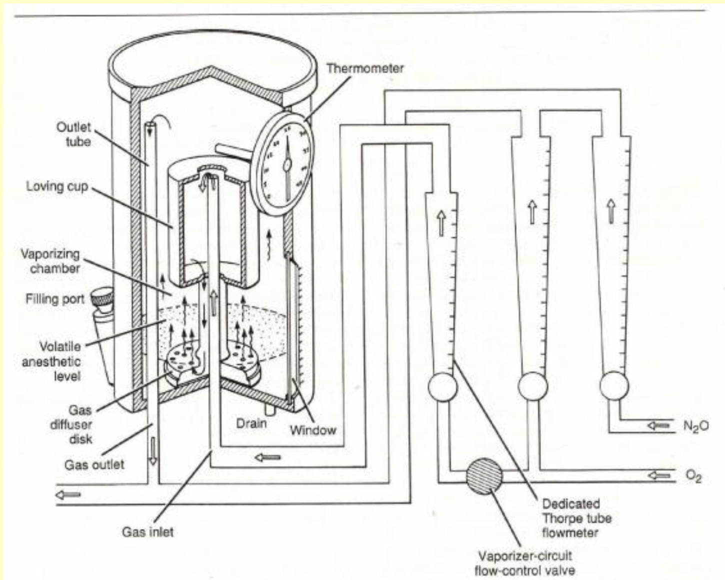
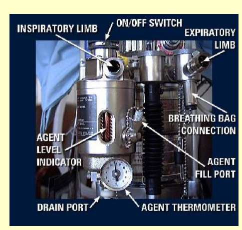


Figure 4–8. The copper kettle vaporizer. (Redrawn and reproduced, with permission, from Hill DW: *Physics Applied to Anaesthesia*, 4th ed. Butterworths, 1980.)

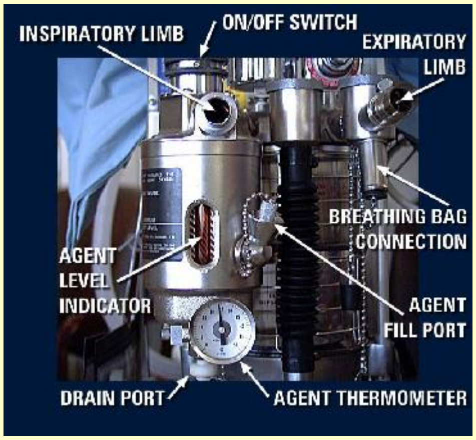
Method of vaporization

Bubble Through

- Carrier gas is broken into small bubbles usually by a mesh screen and bubbled through the liquid anesthetic
- (Copper Kettle, Vernitrol)

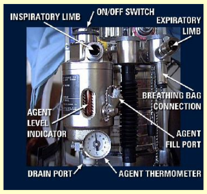


Vernitrol based on Copper Kettle



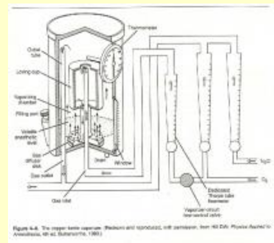
Vernitrol Vaporizer Theory

- Bubble through, non-temperature compensated device that uses a separate flow meter to control the gas flow in the vaporizer.
- The anesthetic vapor produced is then mixed with the fresh gas flow in the circuit



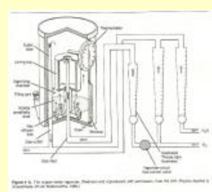
Copper Kettle Math

- VO: Vapor Output (mL/min)
- CG: Carrier Gas Flow (mL/min)
- VP: Vapor Pressure (mmHg)
- BP: Barometric Pressure (760mmHg)
- VAA%: Volatile Anesthetic Agent Concentration



$$VO = \frac{CG \times VP}{BP - VP} \qquad \frac{VO}{VAA\%} = \text{Total Gas Flow}$$

Examples



- Halothane: VP 243 mmHg
- CG: 100 mL/min

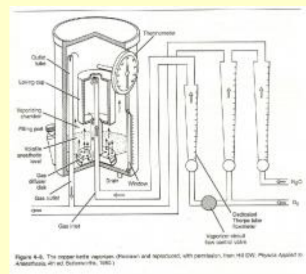
$$VO = \frac{(100\ mL/min)(243mL/min)}{(760mmHg - 243mmHg)} = \frac{24300}{517} = 47mL/min$$

If 1% of Halothane is desired:

$$\frac{47mL/min}{0.01} = 4700mL/min \text{ Total gas flow needed}$$

Halothane

- If 100mL/min of O2 enters Kettle, 147ml of gas will exit (100mL of O2 picked up 47mL of Halothane)
- % Halothane exiting Kettle is 32% (243/760=0.32) at 1 atm
- If Only 1% Halothane needed for anesthesia, the 32% needs to be diluted with 4553mL/min
- 4700mL/min – 147mL/min = 4553mL/min



More Math

- Enflurane: VP 175 mmHg
- CG: 100 mL/min

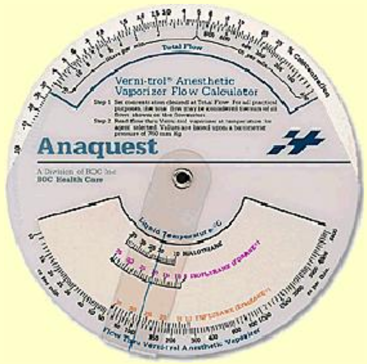
$$VO = \frac{(100\ mL/min)(175mL/min)}{(760mmHg - 175mmHg)} = \frac{17500}{585} = 30mL/min$$

If 1% of Enflurane is desired:

$$\frac{30mL/min}{0.01} = 3000mL/min \text{ Total gas flow needed}$$

3000ml/min-130ml/min=2870ml/min

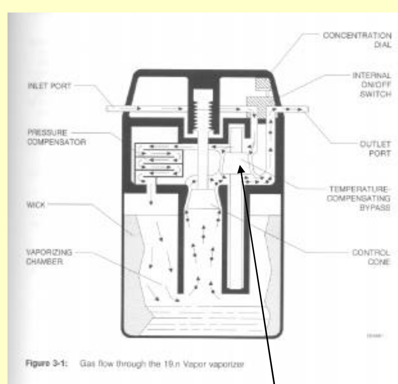
More Math



Temperature compensation

Thermocompensation

- Vaporization causes energy (heat) to be lost.
- Decreased temperature decreases vapor pressure.
- To prevent fluctuations in vaporizer output owing to temperature changes compensatory mechanisms are built in
- Use of a valve that changes flow through vaporizer based on temperature
  (temp compensating bypass)



Method of vaporization

Injection

- Liquid anesthetic or pure vapor is injected into volume of gas.
- If both the volume of carrier gas and anesthetic volume are known, control of vapor concentration can be calculated.
- Gas/Vapor blender (heat produces vapor, which is injected into fresh gas flow)
- Dual circuit (carrier gas is not split)
- Electrically heated to a constant temp
- (Datex-Ohmeda Tec 6)

Temperature compensation

Supplied Heat

- Maintains a constant temperature by electric heater.
- Example Tec 6 Desflurane vaporizer

•Low boiling point 22.8C causes unpredictable output
Supplied Heat (Must be connected to electrical outlet):

•Warms liquid Desflurane to 39C to achieve a pressure of 1,500 mmHg

•Controls gas output by variable resistance via a differential pressure transducer

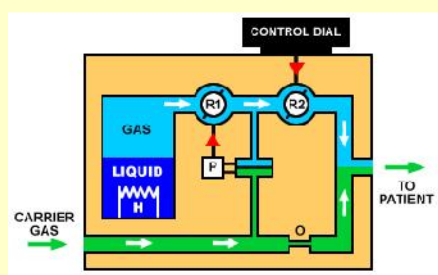
TEC 6

- Designed for the delivery of Desflurane
- Electronic vaporizer which heats Desflurane to maintain constant temperature and vapor pressure for consistent output
- It has an LED display which indicates vaporizer status - no output, low agent, warm-up, operational and alarm battery low
- Features several intrinsic vaporizer monitors and alarms that constantly monitor vaporizer status.

Tec 6

-The major problem presented by Desflurane is that it is extremely volatile: at 22.8C (boiling point) is only slightly above normal room temperature, which precludes the use of a normal variable-bypass vaporizer.

-The Tec 6 vaporizer avoids this problem by heating the Desflurane liquid to above its boiling point in a sealed chamber and mixing pure Desflurane gas with the carrier gas.



Vaporization Terms

*Vapor Pressure- Pressure exerted on walls of a container by molecules that broke away from the liquid surface. Equilibrium will be achieved if temperature remains constant. All volatile anesthetics have a specific vapor pressure. The concentration can be calculated from the vapor pressure above the liquid.

*Boiling Point of liquid- The temperature at which the vapor pressure is equal to atmospheric pressure (T when VP = BP).

*Heat of Vaporization- The number of calories needed to convert 1Gm (1ml) of liquid into a vapor. (e.g. Halothane 20C, Isoflurane 25C, Desflurane 39C). Agent-specific Vaporizer needs to keep the Heat of Vaporization inside constant

More Definitions

- Partial pressure- The pressure exerted by a gas in a mixture is proportional to its percent of that mixture. The total pressure exerted by a mixture of gases is the sum of all its component partial pressures.
- Volumes Percent(Vol. %)- The number of units of volume of gas in relation to a total of 100 units of volume for the total gas volume.
- Boiling Point: Temperature at which all the liquid is in the vapor phase
  - (e.g. Halothane 50C, Isoflurane 48C, Sevoflurane 58C, Desflurane 23C)

Tec 6 (Desflurane) Vaporizer

- Desflurane
  - Heat of Vaporization (39C)
  - Boiling point (23C): boils at room temperature
    - Supplied in a closed (sealed bottle) that cannot be opened to air (filled directly into vaporizer)

Definitions

Specific Heat- The quantity of heat required to raise the temperature of 1 Gm (1ml) of a specific substance by 1C.

The higher the Specific Heat, the more heat is required to raise the temperature of the liquid

The most volatile anesthetic agents have:

a) Low boiling point
b) High heat of vaporization
c) High specific heats

DESFLURANE

SVP

- Anesthetics with a high SVP will require a smaller proportion of the total gas flowing through the vaporizer to pass through the vaporizing chamber to produce a given concentration than will anesthetics with a low SVP
- The following table shows the SVP of some anesthetics at 20C and the proportion of the total gas flow required to pass through the vaporizing chamber to produce an output concentration of 1% at a barometric pressure of 760 mmHg:

Agent	SVP (mmHg)	Chamber flow Totalflow
Halothane	243	2.1 %
Isoflurane	239	2.2 %
Enflurane	175	3.4 %
Methoxyflurane	23	32.0 %

Specificity

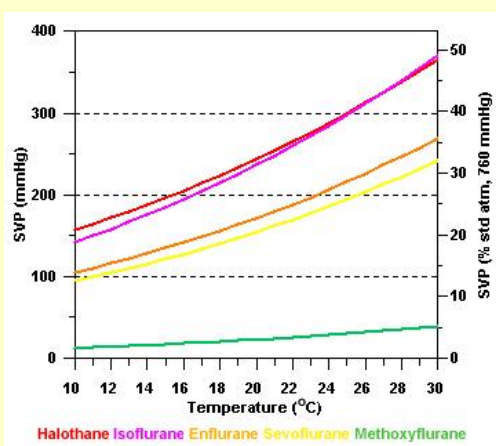
Agent Specific

- Calibrated and constructed for use with only one specific anesthetic agent.
- Must be labeled which anesthetic contained within.
- Use of other agents may give incorrect concentration and may damage vaporizer or cause harmful byproducts.
- Question: If Halothane was inadvertently put into an Ethrane (Enflurane) vaporizer would the anesthetic concentration be equal to, less than, or greater than the dialed desired concentration? (higher)
- Enflurane SVP=175mmHg
- Halothane SVP=243mmHg

Wrong Agent

- It can be **extremely dangerous** to deliver anesthetics from vaporizers for which they were not designed.
- A vaporizer intended for use with methoxyflurane (SVP=23) filled with isoflurane (SVP=239) and with the dial set to 1% would in fact be producing about 15 % isoflurane.
- What about filling an Ethrane (Enflurane) vaporizer with Halothane???? (lower [] results)

Saturated vapor pressure varies as a function of temperature



Specificity

Multiple Agent

- Rarely in use and not advised.
- May be used with multiple agents
- Must be labeled with agent agent contained within.

Resistance

Low Resistance

- Low resistance allows placing vaporizer within the breathing system.
- Vaporization accomplished by ventilatory gas flows.
- The OMV is particularly versatile, since the same vaporizer can be used to vaporize a number of agents with only the dial scale being changed

Oxford Miniature Vaporizer

Ideal Gas Law

Gases behave predictably. This behavior is expressed by the:

IDEAL GAS LAW

PV= nrT

P= Pressure
V= Volume
n= number of moles of gas
r= ideal gas law constant
T= Temperature

Inhalation of foreign substances

Causes include:

*Absorbent dust
*Residual ethylene oxide or glycol
*Contaminants in compressed air
*Breathing system components, and foreign bodies

Preventing or detecting foreign substances:

*Assessment of patient and machine during set up and use
*Airway obstruction will cause high airway pressure alarms to sound
*Use of filter on breathing Circuit
*Never release bag pressure at Y-connect (use APL valve)

Overdosing

Overdose causes:

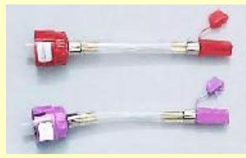
*Tipping of vaporizer (more liquid will go into bypass area)
*Vaporizer inadvertently turned on or never turned off from previous use
*Overfilled vaporizer
*Simultaneous use of vaporizers on older machines without interlock system (if center vaporizer is removed, place remaining 2 together)
*Incorrect calculations with measured-flow vaporizers (Copper Kettle)
*N_2O flowmeter bobbin or float stuck at top of Thorpe tube
*Pumping effect due to inspiratory positive pressure from manual or assisted ventilation or use of O2 flush valve transmitted back to vaporizer. Seen with low flows.

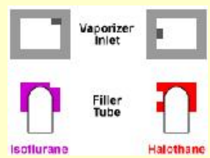
Inadequate dose

Inadequate dose causes:

Light anesthesia is not always as serious, but may be deleterious
*O_2 flowmeter bobbin or float stuck at top of Thorpe tube
*Disconnect that allows air to be entrained into breathing system
*Repeatedly using flush valve diluting concentration
*Leak in bellows
*Empty vaporizer or leak in vaporizer
*Incorrect calculations with measured-flow vaporizers
*Pressurizing effect- due to inspiratory positive pressure from manual or assisted ventilation or use of O2 flush valve transmitted back to vaporizer. Seen with high flows.

Fillers



Classification	Datex-Ohmeda: Tec4, Tec 5, Aladin (can use De Drager: Vapor 19.n, Vapor 2000	Copper Kettle, Vernitrol	Datex-Ohmeda: Tec 6 (Desflurane
Splitting Ratio (Carrier Gas Flow)	Variable-Bypass (vaporizer determines carrier gas split)	Measured-flow (operator determines carrier gas split)	Dual-circuit (carrier gas is not split)
Method of Vaporization	Flow-over (including Aladin)	Bubble-through	Gas/Vapor blender (heat produces vapor, which is injected into fresh gas flow)
Temperature Compensation	Automatic	Manual (by changes in flow)	Thermo controlled (heated to 39C)
Calibration	Calibrated to agent	Multiple agents	Calibrated to agent